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CAUSE AND PREDICTION OF BEACH EROSION

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Eastern Region
Garden City, NY

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NOAA TECHNICAL MEMORANDA
National Weather Service, Eastern Region Subseries

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UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE EASTERN REGION
Garden City, New York

NOAA TECHNICAL MEMORANDUM NWS ER-55

CAUSE AND PREDICTION OF BEACH EROSION

Stanley E. Wasserman
and
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National Weather Service
Eastern Region Headquarters

SCIENTIFIC SERVICES DIVISION
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November 1973

CAUSE AND PREDICTION OF BEACH EROSION

I. OCEANOGRAPHIC AND METEOROLOGICAL FACTORS INVOLVED IN BEACH EROSION

Intense beach erosion is always a possibility when prolonged periods of high waves with a short wavelength affect the coastline. This wave action is especially bad during periods of unusually high tides. In the Eastern Region, these conditions can develop with a strong, east-coast storm, especially a slow moving one, or when stationary weather systems cause a long, steady fetch. While hurricanes and tropical storms do cause major damage along the beaches, they are not considered in this study.

The most damaging beach erosion is caused by a fetch directed along the coastline with an onshore component. The wind-driven steep waves stir up the sand and fine gravel and tend to eat away at the beaches. Then, a longshore current, or "littoral drift" is required to transport the loosened sand, if the erosion process is to continue. High tides, that are necessary for the erosion process to penetrate inland above the normal beach line, can be due to storm surges, lessening atmospheric pressure on the adjacent ocean surface, or the direction of the long-shore current, in addition to the normal astronomical tides. The importance of astronomical tides should be emphasized, especially in the timing of the most intense erosion. A particular storm has a high damage potential during the time of spring tide. (This occurs twice each month at the times of new and full moon.) If the spring tide occurs when the moon is closest to earth (perigee), then the astronomical tides are even greater. The most severe case of Atlantic coast erosion this century occurred during a spring tide in March 1962, with the moon near perigee. Additional information concerning this storm is presented by Stewart (1962) and by Cooperman and Rosendal (1963).

The direction of the longshore current is important due to the effect of the earth's rotation (coriolis acceleration) in causing water to be piled up to the right of a current's direction. Thus, longshore currents with the shore to the right contribute to inland penetration of erosion. Hence, along the Atlantic coast of the United States, wind-driven currents in the direction from Maine to Florida, associated with strong northeasterly winds, scrub away at the shoreline and erode the beaches. These wind-driven currents can break down into cyclonic eddies which erode in such a way as to produce a scalloped configuration.

Tank experiments have provided a relationship between the rate of littoral transport of sand and deep-water wave steepness. The tests were conducted for various angles of approaching deep-water waves relative to the beach orientation. Wave steepness is defined as the ratio of wave height over wave length (H_o/L_o). Results presented by Johnson (1953) (Figure 1) show that the maximum rate of littoral transport occurred if the wave steepness was between 0.02 and 0.03 and the angle of the approaching deep water wave was about 30°. According to Johnson (1953), storm waves with steepness values exceeding 0.025 may remove large quantities of sand from beaches but they appear to move the material offshore into deeper water, where an offshore bar starts to form. An offshore bar reduces the ocean's ability to further transport sand away from the beaches. Eventually, the material in the offshore bar can be moved back to the beach by the action of a sustained period of waves with small steepness.

Johnson, in referring to the tank experiment, stressed that "*....possible application to field conditions should be accompanied by the words of caution that the tests pertain to one sand size and to a beach of infinite length under equilibrium conditions. Also, it should be recognized that the test conditions involved neither the effect of tide nor a change in the character of the waves.*"

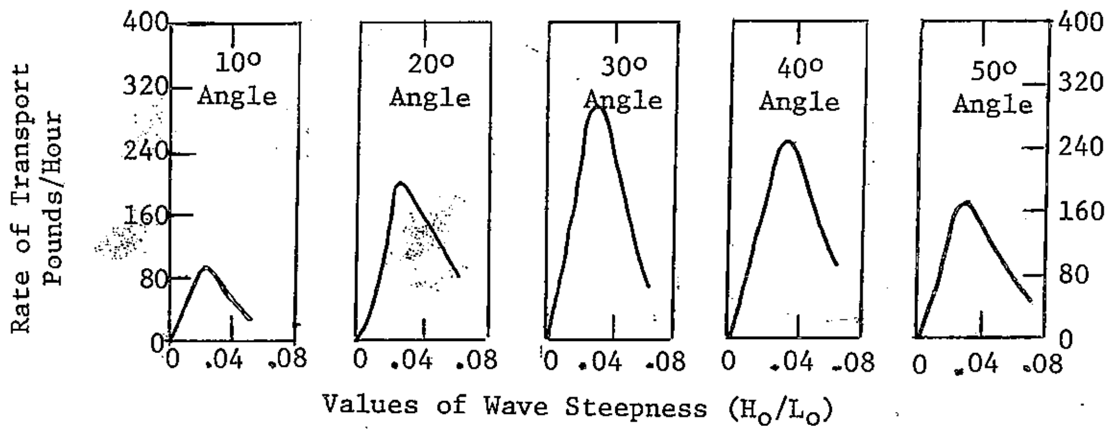

Figure 1. *Relationship between rate of littoral transport and wave steepness for various indicated angles of wave approach. (After Johnson 1953)*

It is difficult to apply the tank experiment results directly to the beaches because of the dearth of measured wave data and the lack of measurements of rate of sand transport and erosion that can result. An indirect application of the results is possible, however, if we consider that sea level atmospheric conditions create the winds that, in turn, create the waves that have been shown in the laboratory to be related to sand transport.

II. SEA-LEVEL WIND AND PRESSURE FIELDS ASSOCIATED WITH BEACH EROSION

Dates of beach erosion events along the Atlantic coast were determined from information collected by National Weather Service Offices. The incidences of erosion were by no means complete since no records have been kept and they were compiled from memory. Most cases, therefore, are for the past few years, with only the most extreme cases of inland penetration of beach erosion recalled prior to that. Cases up to September 30, 1972, were considered in this study, although many cases subsequent to that date have recently been reported.

Sufficient cases for further evaluation in this study were obtained for only two areas along the Atlantic Coast, the New Jersey shoreline, and the south shore on Long Island. The National Meteorological Center (NMC) 3-hourly surface analyses were examined to determine if we can recognize characteristics that accompany the development of ocean conditions that caused beach erosion in these areas. The following were noted for each case:

1. The synoptic pressure pattern.

2. The angle the predominant observed wind direction made with the coastline— This angle was determined from 3-hourly maps prior to and during the time of erosion. The coast was assumed as straight for a broad expanse up and down the coast from where the erosion was reported, and the wind direction was averaged for this broad expanse. It is assumed that this parameter is related to the angle of approaching deep-water waves.

3. The setup time — This is defined here as the duration in which observed coastal winds were within $\pm$ 20° from the wind direction as determined for step 2, above. A long setup time should be conducive for wave development.

4. The longest fetch out from the coastline under consideration that existed during the setup time — Fetch is defined here as the distance out to sea in which the wind direction at a given 3-hourly time did not vary by more than $\pm$ 20° from the wind direction at the shoreline. Wind direction over the ocean was inferred from ship reports and pressure analysis. A long fetch should be conducive to wave development favorable for beach erosion.

5. The strongest pressure gradient measured along the fetch during the setup time. This was determined from the spacing between isobars as drawn for 4 mb. intervals on the NMC analysis. A strong pressure gradient should be conducive for wave development favorable for beach erosion.

Results will now be discussed separately for New Jersey erosion cases and for Long Island erosion cases.

NEW JERSEY CASES

The synoptic pressure patterns for the eleven New Jersey cases are now summarized. In all cases, at the beginning of the setup time a high pressure center (8 cases $\geq$ 1030 mb.) was located over southeastern Canada. The high pressure center slowly moved, or ridged, eastward during the setup period with slight decrease in central pressure. Intensification of the pressure gradient off the New Jersey shore resulted as a low pressure system usually, but not always, developed somewhere between Florida and Norfolk, VA, with occlusion of the frontal system occurring between the latitudes of Hatteras and southern New Jersey. In two cases, two low pressure systems developed in rapid succession rather than one slow-moving system, and in two other cases there was persistent northeasterly flow from a strong Canadian High with no low pressure center developing to the south.

Composite sea-level pressure maps for the eleven cases were prepared from mean values of pressure determined for selected geographical points for the beginning, middle, and end of the setup time, as well as for 12 hours after the setup time (Figure 2). (As mentioned earlier, the setup time is the duration in which the coastal winds were within $\pm$ 20° of a predominant wind direction that existed at the shoreline prior to and during the erosion event.) The average setup time for the eleven cases for which the composites were constructed was 35 hours, but varied from 18 hours to 51 hours. The main features of the composite maps are the slowly eastward-moving high pressure system over southeastern Canada and the slow, northeastward movement of a deepening Low off the east coast of the United States. A very strong pressure gradient developed off the New Jersey coast during the setup time with a long over-~~water~~ geostrophic wind fetch.

All eleven cases occurred in either the fall (between mid-September and mid-November) or in the late winter through early spring (from February through mid-May). There were no extra-tropical cases reported in the months of June, July, and August, or in December and January. The lack of beach erosion reports for December and January is due to the small data sample, as evidenced by the fact that two cases were reported in December 1972, subsequent to the period included in this study.

Results of the measurement of the four remaining factors mentioned previously (Items 2 through 5, above) are listed in Table 1 for each of the 11 cases. The cases are listed in ascending order of maximum pressure gradient. Additional observations regarding the New Jersey cases are as follows:

1. The angle that the predominant wind direction made with the assumed smoothed shoreline orientation for each of these cases agrees well with the discussion presented earlier and with the tank studies conducted by Johnson (1953). All cases had angles of between 20° and 40° with 30° predominating. The New Jersey coast orientation was taken such that a wind direction of 30° was parallel to the coast.

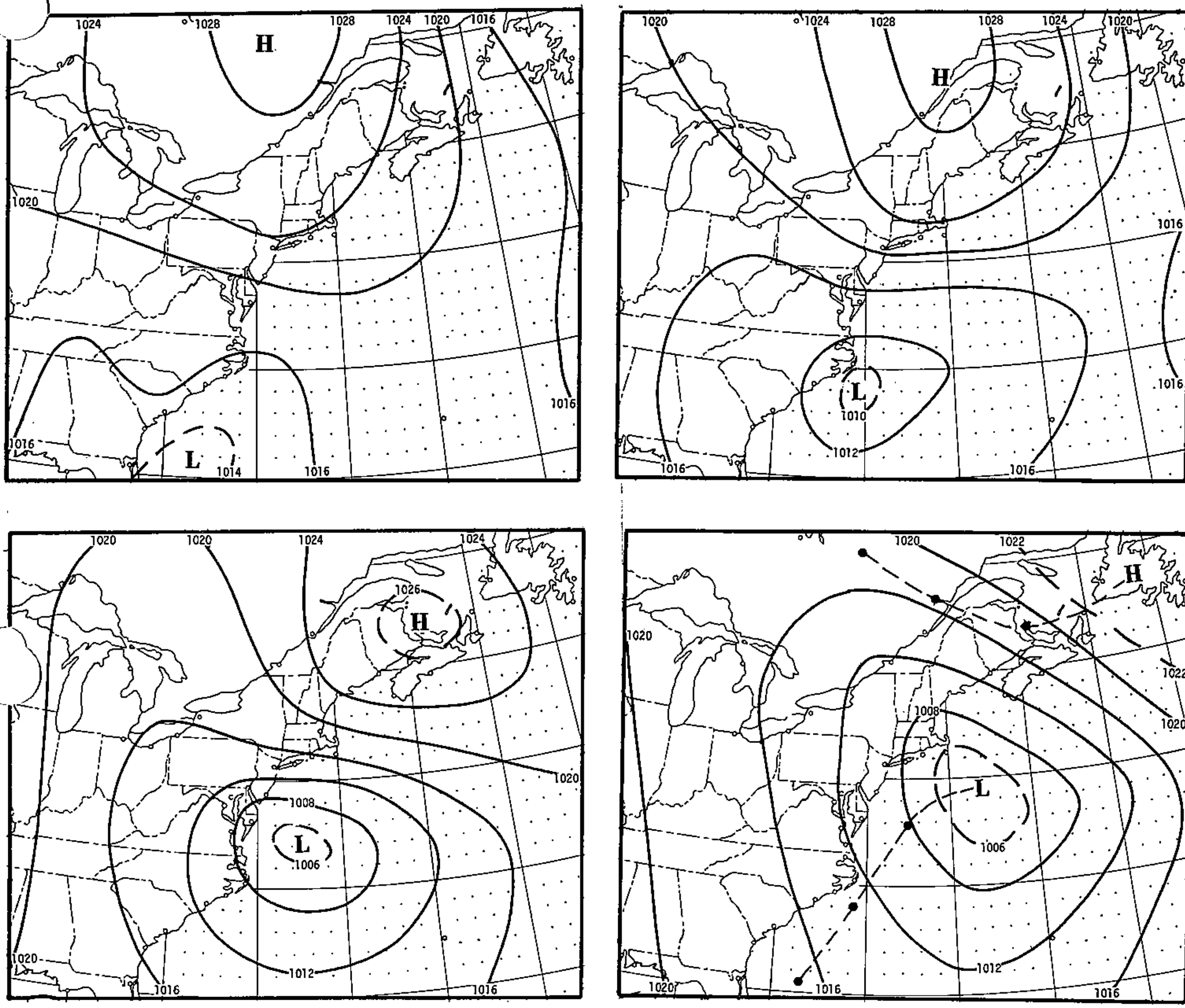

Figure 2. Composite sea level pressure maps for the beginning (upper left), middle (upper right), end (lower left), and 12 hours after the end (lower right) of the setup time for 11 cases in which beach erosion occurred along the New Jersey Shore. The setup time is the period during which the coastal winds were within plus or minus 20^{0} of a predominant wind direction that existed prior to and during each erosion event. The path and positions of composite Highs and Lows are indicated on the lower right chart.

Date	Angle Between Predominant Wind Direction and Shoreline	(A) Setup Time (Hours)	(B) Maximum Fetch Lengh (n.m.)	(C) Minimum Distance (n.m.) Between 4 mb. Spaced Isobars Along Fetch*	Beach Erosion Potential Index (A) x (B) / (C)
		NEW JERSEY CASES			
Sep. 19-20, 1971	30°	33	600	110	180
Oct. 21, 1971	30°	33	650	100	214
Sep. 21, 1972	30°	36	625	50	450
Feb. 2-3, 1972	40°	39	700	40	683
Mar. 14-15, 1972	40°	42	550	40	578
Mar. 27-28, 1971	30°	27	450	40	304
Feb. 17-19, 1972	30°	51	750	30	1275
May 10, 1972	20°	18	450	30	270
Nov. 12, 1968	30°	24	400	30	320
Mar. 6-8, 1962	40°	48	650	25	1248
Apr. 6-7, 1971	30°	39	300	25	468
		LONG ISLAND CASES			
Nov. 12-14, 1970	10°	30	600	75	240
May 23-25, 1967	10°	39	700	70	390
Feb. 3-4, 1972	10°	42	700	40	735
Nov. 6-8, 1963	0°	27	450	40	304
Feb. 18-19, 1972	0°	54	750	30	1350
Mar. 1, 1968	0°	18	600	30	360
Nov. 12-13, 1968	10°	27	400	30	360
Feb. 13-14, 1972	20°	18	300	30	180

* This is an indication of the maximum pressure gradient that existed along the fetch at any time during the setup time.

TABLE 1. *METEOROLOGICAL CONDITIONS ASSOCIATED WITH BEACH EROSION.*

2. With weaker pressure gradients ($\leq$ 4 mb./50 n.m.) a long maximum fetch ($\geq$ 600 n.m.) and a long setup time ($\geq$ 30 hours) is needed.

3. With more intense storms whose pressure gradients are greater than 4 mb./50 n.m., a maximum fetch as small as 300 n.m. or a setup time as short as 18 hours produced erosion.

The concept of a beach erosion potential index is now introduced. This index is defined as the setup time (in hours) multiplied by the maximum fetch length (in nautical miles) that existed during the setup time, divided by the minimum distance (in nautical miles) that existed between 4 mb. spaced isobars along the fetch during the setup time. While this index may provide useful information concerning the storm wave's potential for causing beach erosion, we must also consider the effects of tides, the angle of approaching deep-water waves, and the vulnerability of the beaches to erosion process - including such things as bottom topography and construction of protective barriers. Beach erosion potential values are presented in Table 1 for the cases examined. Future studies may reveal a relationship between beach erosion severity and a beach erosion potential index, but no conclusions were obtainable here.

LONG ISLAND CASES

Eight cases were investigated in which erosion was reported on the south shore of Long Island (Table 1). The general synoptic situations were somewhat similar to the New Jersey cases in that a High was always present over southeastern Canada. Three of these eight cases were with storms in which erosion also occurred in New Jersey, but at a different time during the storm.

In seven of the eight cases, a strong Low passed within 150 n.m. south or southwest of Long Island. In the remaining case, a Low passed 200 n.m. southeast of Long Island, with a ridge present just north and west of Long Island. The angle the predominant wind direction made with the coast in all but one case was either 0° or 10°. In the remaining case, the angle was 20°. This finding is different from the New Jersey results and different from the 30° angle that would be expected from tank experiments. A possible explanation for this difference is that the true orientation of the coastline at the locations where the erosion occurred may have been different than the smoothed orientation of 70° assumed for all of Long Island. Also, it was noted in all eight cases that, near the end of the setup period, the wind shifted 20° clockwise from the predominant wind direction. It is possible that most of the erosion occurred during this short period in which the winds made an angle of near 30° with the smoothed coastline. The precise time and rate of erosion is, unfortunately, not known. In any event, it is considered significant that in each of the Long Island cases, the predominant wind direction was either 70°, 80°, or 90°, and that the winds shifted to east-southeast near the end of the setup period.

Composite sea-level pressure maps for the eight Long Island cases are presented for the beginning, middle, and end of the setup time, as well as

12 hours after the setup time (Figure 3). The main features of these composite maps are the high pressure system moving slowly eastward through southeast Canada and the explosive deepening of a Low while the Low moves northward along the east coast. An intense pressure gradient develops between these two systems with a strong east-southeasterly geostrophic wind affecting Long Island, becoming southeasterly at the end of the setup time.

There are some significant differences between the New Jersey erosion composite maps and those for Long Island. For erosion in Long Island, the composite Low is deeper and its path closer to the coast. During the setup time, the High moves initially northeasterly and then easterly for Long Island erosion, whereas for New Jersey erosion the High moves initially southeasterly and then easterly. Finally, the geostrophic wind direction off the Long Island and New Jersey coasts is easterly for the New Jersey erosion composite maps, but southeasterly for Long Island erosion.

III. PREDICTION OF METEOROLOGICAL CONDITIONS ASSOCIATED WITH BEACH EROSION

Forecasters must be continuously alert to the potential for beach erosion, and they should issue suitable statements when the potential is great enough to cause concern. Information presented in the previous sections should enable a forecaster to recognize when past and current conditions are favorable for beach erosion at least in the areas discussed. In this section, we present guidance material that is available to assist the forecaster in determining if future conditions will remain favorable for beach erosion.

The numerical prediction products that should be referred to in identifying the potential for beach erosion are now listed.

1. LFM 12- and 24-hour sea level pressure progs (NAFAX charts 22, 25, 88, 91).

2. SUM sea-level pressure progs (FOFAX charts 051, 112).

3. PE model 24, 36, 48-hour sea-level pressure progs (FOFAX charts 37, 38, 39, 101, 102, 103).

4. Trajectory model 24-hour surface trajectories (teletype Circuit "C", FOUS bulletins, and FOFAX charts 050, 119).

5. 24- and 36-hour wind wave and combined sea height progs, 36-hour swell prog (FOFAX charts 57, 58, 59, 122, 123, 124).

6. 6-hourly storm surge forecasts out to 48 hours (RAWARC teletype circuit, unscheduled but generally transmitted near 0700Z and 1900Z as FZUS 3 message).

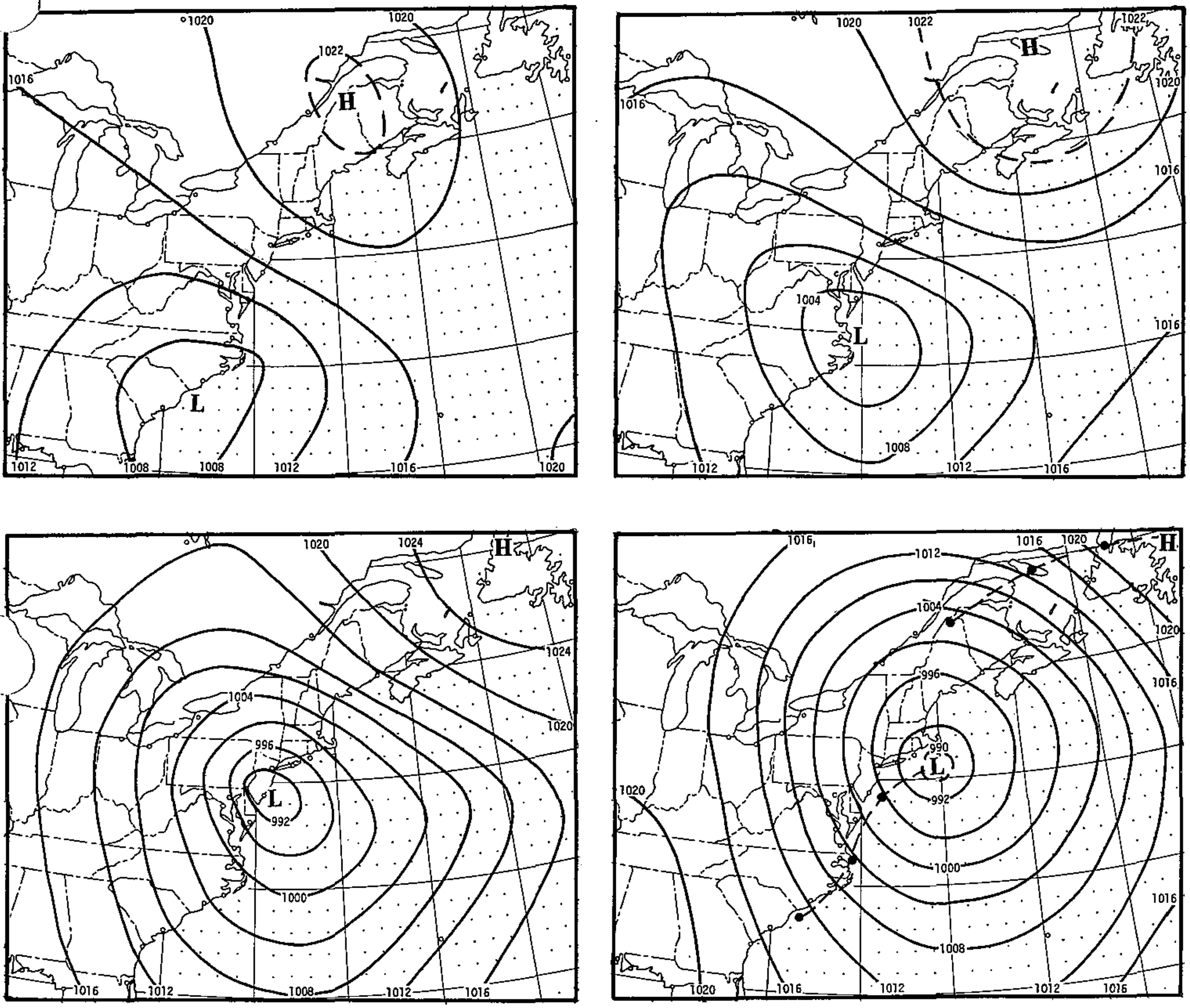

Figure 3. Composite sea level maps for the beginning (upper left), middle (upper right), end (lower left), and 12 hours after the end (lower right) of the setup time for 8 cases in which beach erosion occurred along the South Shore of Long Island. The setup time is the period during which the coastal winds were within plus or minus 20^{0} of a perdominant wind direction that existed prior to and during each erosion event. The path and positions of composite Highs and Lows are indicated on the lower right chart.

7. Objective surface wind forecasts based on model output statistics (available on request/reply capability of service "A" and updated daily around 0745Z and 1945Z).

Items 1 through 4, above, are guidance for predicting the surface pressure fields and resultant winds. Item 5 is guidance for predicting wave heights, and, although designed for deep-water waves in the open ocean, can be used as an indirect indicator of rough surf and longshore currents. Item 6 presents guidance as to storm surge that can be expected at selected east coast locations. Item 7 presents surface wind forecasts for selected east coast locations.

In addition to the numerical guidance listed above, field forecasters should be aware of NMC subjective modifications to the numerical surface progs as indicated in NMC subjective surface pressure progs transmitted on NAFAX and discussions that appear both on teletype Circuit "C" and NAFAX (charts 38, 102).

Pore (1973) presents examples of automated forecast products mentioned in items 3, 5, and 6, above, as they apply to observed and predicted marine conditions for the Atlantic coastal storm of February 18-20, 1972. This storm did produce erosion along the New Jersey and southern Long Island beaches and is included as cases in Table 1. Brown and Younkin (1973), in their discussion of the NMC's performance in forecasting for this same storm, present examples of the automated forecast products mentioned in items 1, 3, and 6, above. They also present examples and a discussion of the important subjective modifications that NMC makes to the numerical forecasts.

IV. CONCLUSIONS

Oceanographic and meteorological factors involved in beach erosion can be isolated. Surface wind and pressure conditions associated with known beach erosion cases have been presented, and products operationally available to assist in predicting these conditions have been itemized. It is not known how often beach erosion does not occur when the wind and pressure conditions are favorable. Shifting sands, which continuously change the near coastal underwater topography, and tide conditions play an important role in controlling the beach erosion process.

Significant meteorological conditions found to exist during reported beach erosion events along the New Jersey coast and the south shore of Long Island consist of the following:

(See composite charts, Figures 2 and 3).

1. A high pressure system ridging or moving slowly through southeast Canada.

2. An angle that the predominant wind direction makes with the coastline of between 0^{o} and 20^{o} for Long Island and between 20^{o} and 40^{o} for New Jersey.

3. A setup time of at least 18 hours, but varying upward according to fetch and pressure gradient.

4. A fetch of at least 300 n.m., increasing to at least 600 n.m. when the pressure gradients along the fetch and during the setup time do not reach an intensity of at least 4 mb./40 n.m.

5. A pressure gradient of at least 4 mb./110 n.m. occurring somewhere along the fetch and during the setup time.

These findings were based on a small data sample and may change as more data become available.

V. FUTURE PLANS

The findings presented in this paper will be tested and modified as new cases become known. Since the cases used in this study were compiled from memory and are incomplete, the authors solicit information pertaining to additional beach erosion events that occurred anywhere along the Atlantic coast.

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(Continued from inside front cover)

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